Detector R&D on Auxiliary Subsystems

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for the BNL EIC Science Task Force

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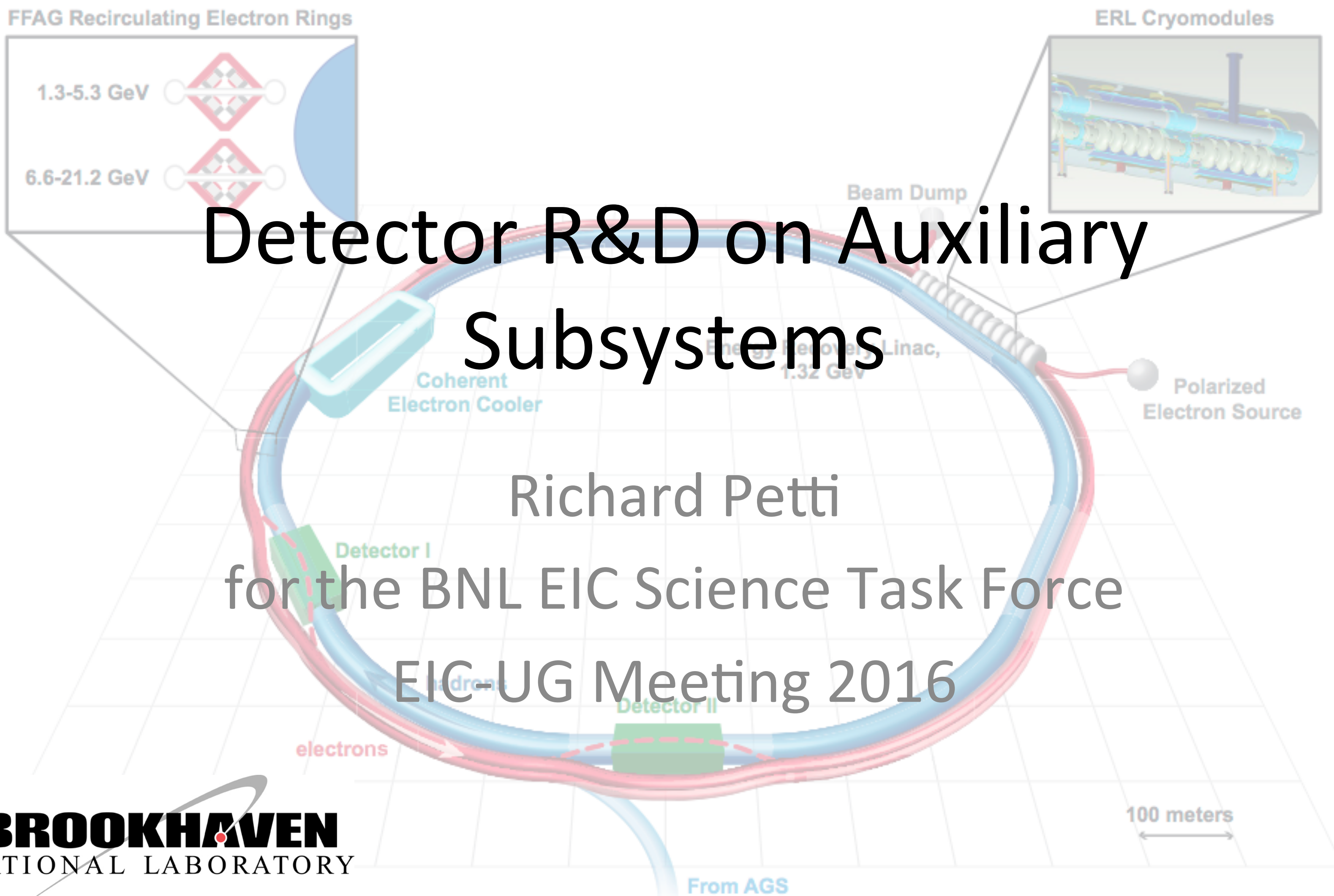
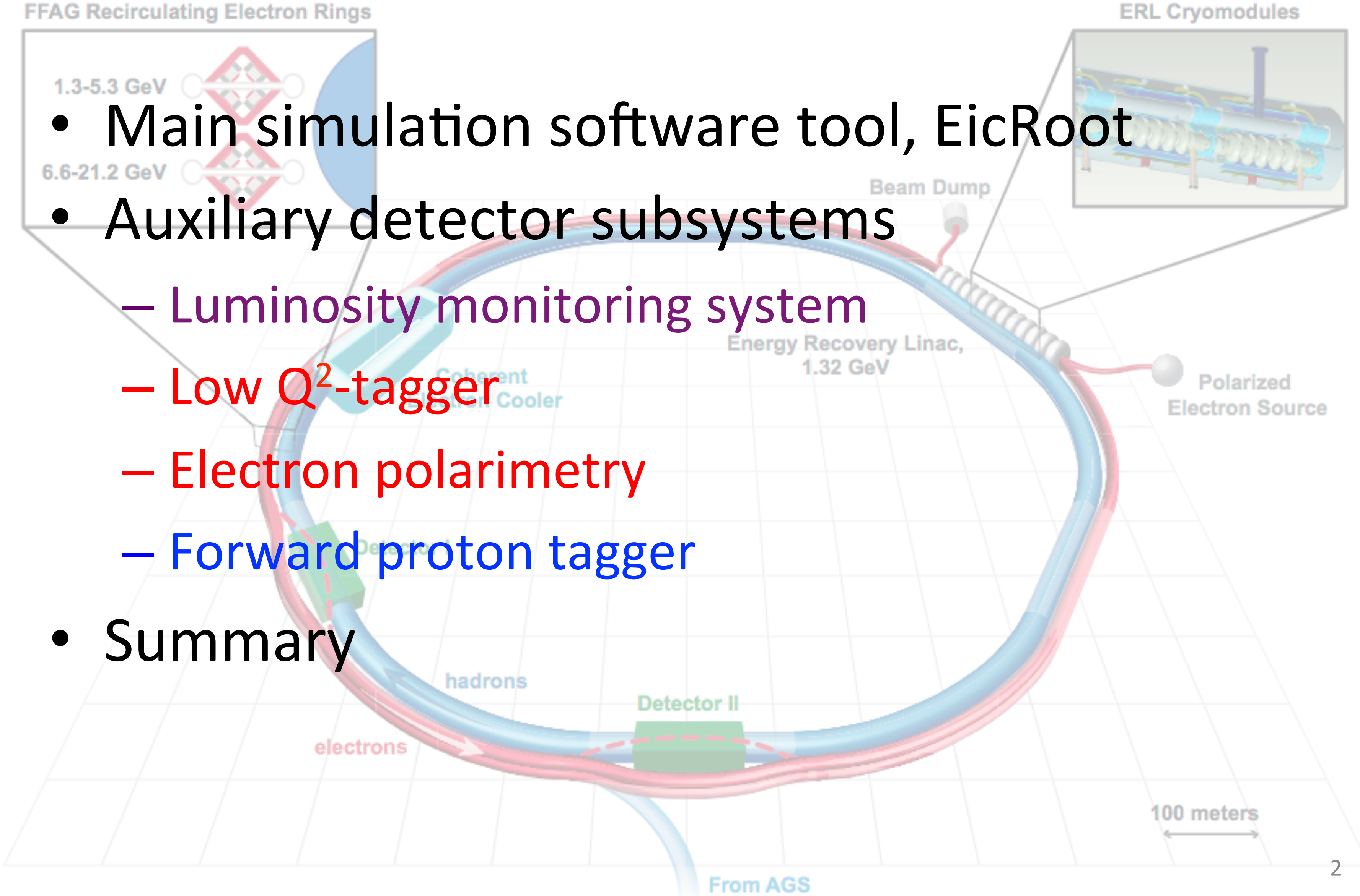


BROOKHAVEN NATIONAL LABORATORY

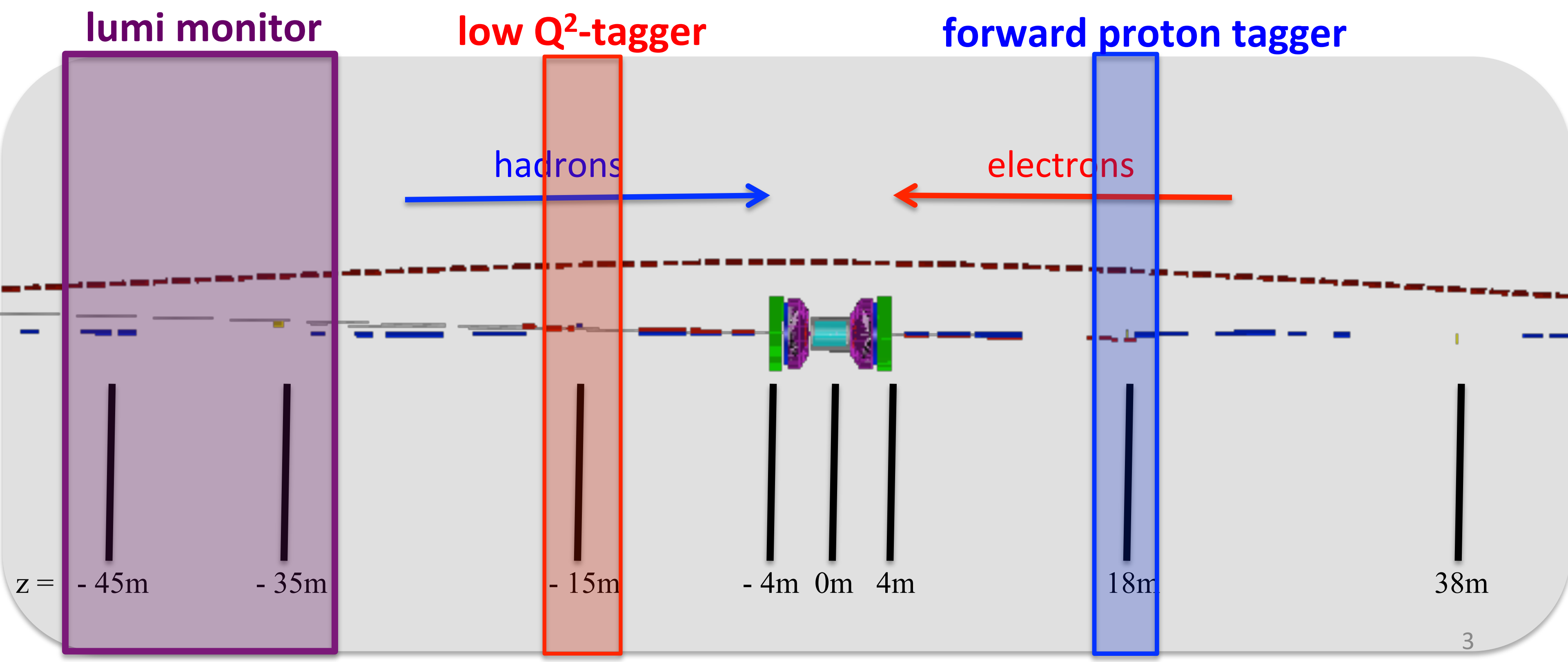
Outline

- Main simulation software tool, EicRoot
- Auxiliary detector subsystems
  - Luminosity monitoring system
  - Low Q^2-tagger
  - Electron polarimetry
  - Forward proton tagger
- Summary



Simulation Tools: EicRoot

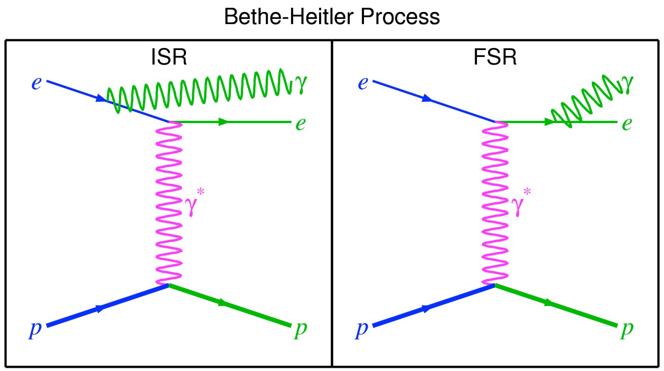
- Incorporate machine lattice into EicRoot
  - https://wiki.bnl.gov/eic/index.php/Eicroot
  - Uses ROOT for detector and machine geometry implementation
  - Uses GEANT for particle tracking



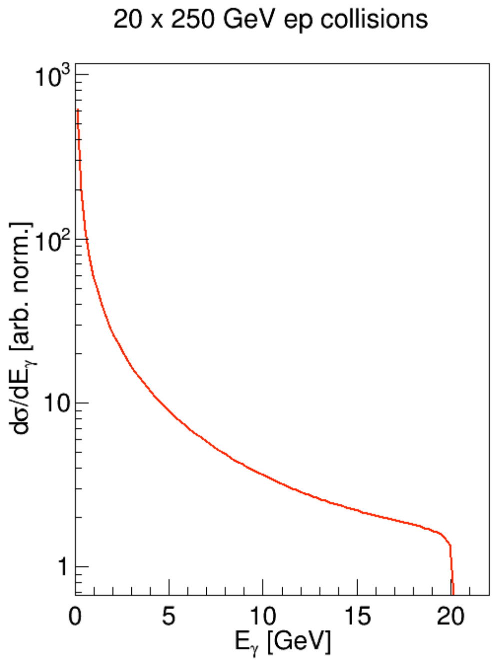
Monitoring the Beam Luminosity

- Measure luminosity via e+p → e+p+γ
  - Well known calculable pure QED process
  - Large cross-section
- Photons are sharply forward-peaked
  - θ_γ is dominated by beam optics
  - Need good control on beam parameters
- Performance requirements:
  - Need to know luminosity better than 1%
  - System needs to be fast enough to give live feedback to machine on luminosity steering
- From measured photon rate, N_γ, photon acceptance, A, and cross section, σ, we can calculate the luminosity, L

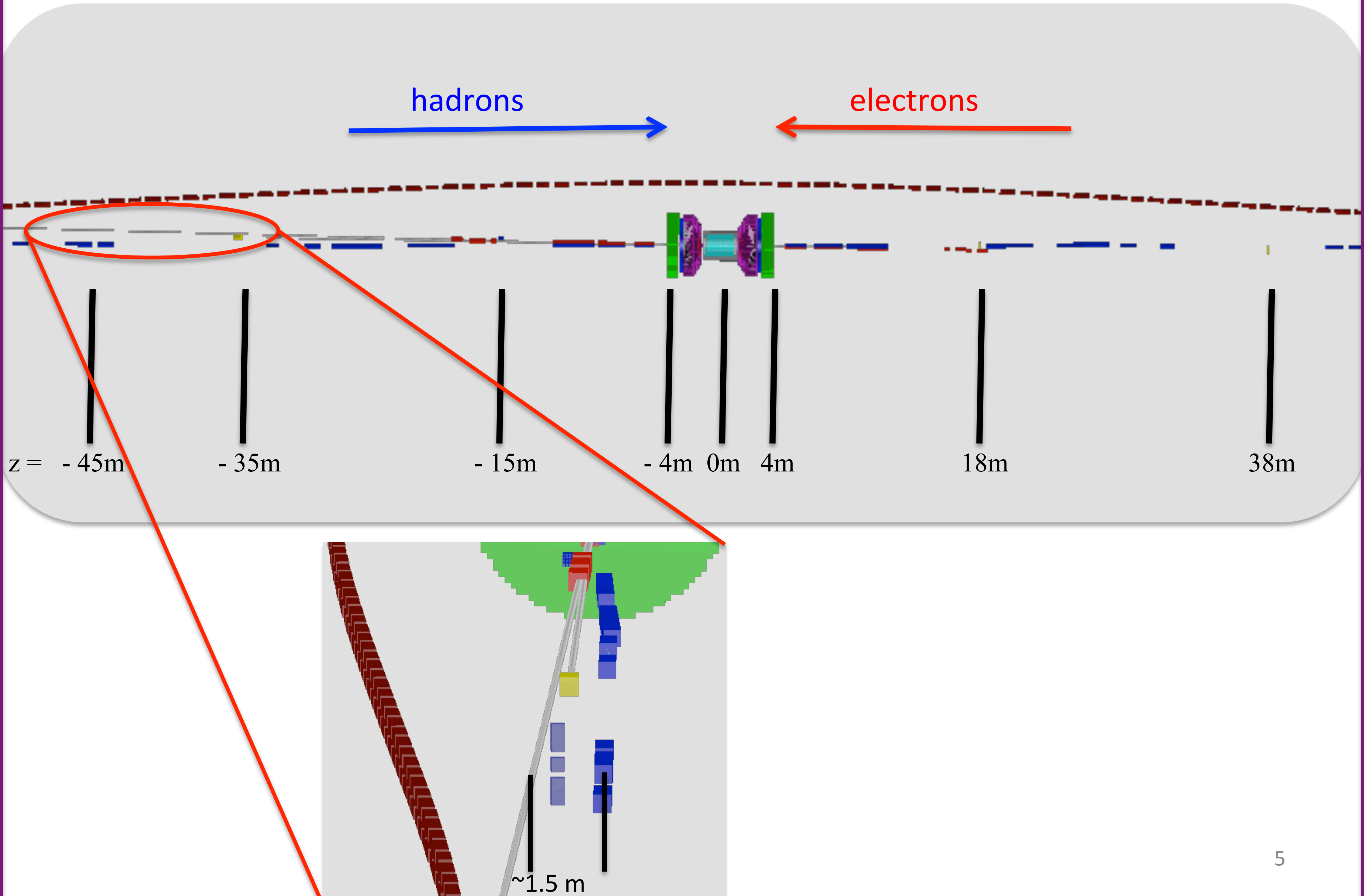
$$L = \frac{N_\gamma}{A\sigma}$$



http://brock.physik.uni-bonn.de/~brock/feynman/misc/bethe-heitler.jpg

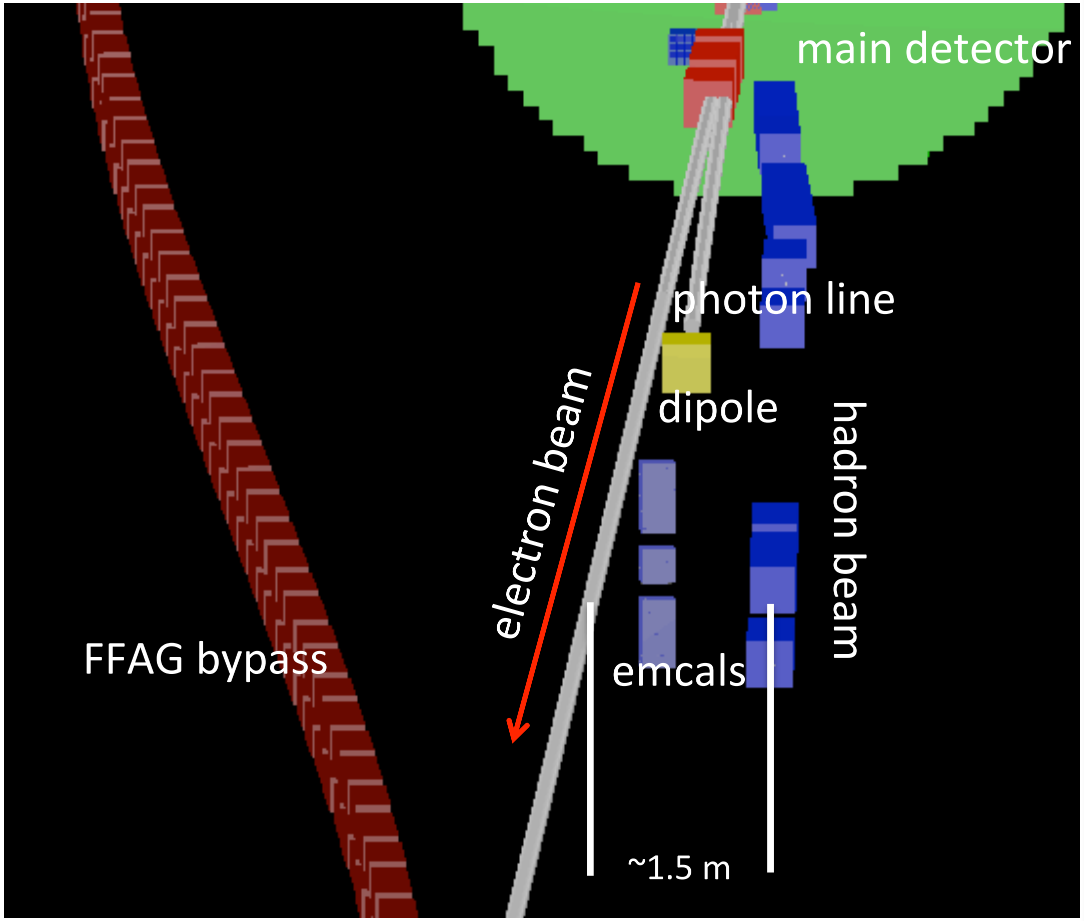


Lumi Placement in the IR



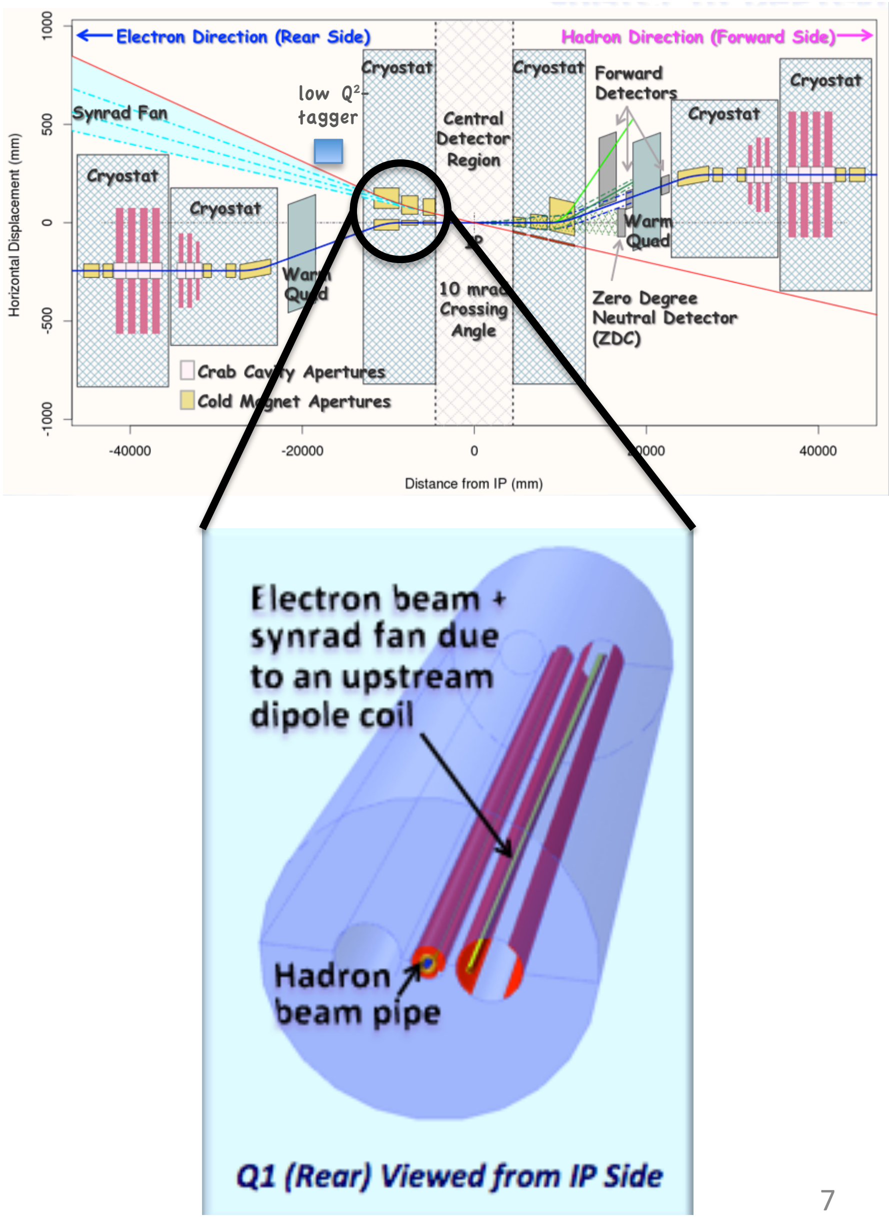
Luminosity Monitoring System: Proposed Configuration

- Main features:
  - Zero degree calo (lzdc)
  - Pair spectrometer
- Allows two measurements with very different backgrounds
  - lzdc in synch. fan
  - Pair spec. not in synch. fan
  - Pair spec is tunable to measure a certain photon energy range
  - Pair spec reduces rate
- Major contributors to uncertainty
  - lzdc: knowledge of acceptance
  - lzcd: pileup
  - lzdc: pedestal shift from synch radiation
  - pair spec: knowledge of acceptance
  - pair spec: converter thickness
  - pair spec: pileup



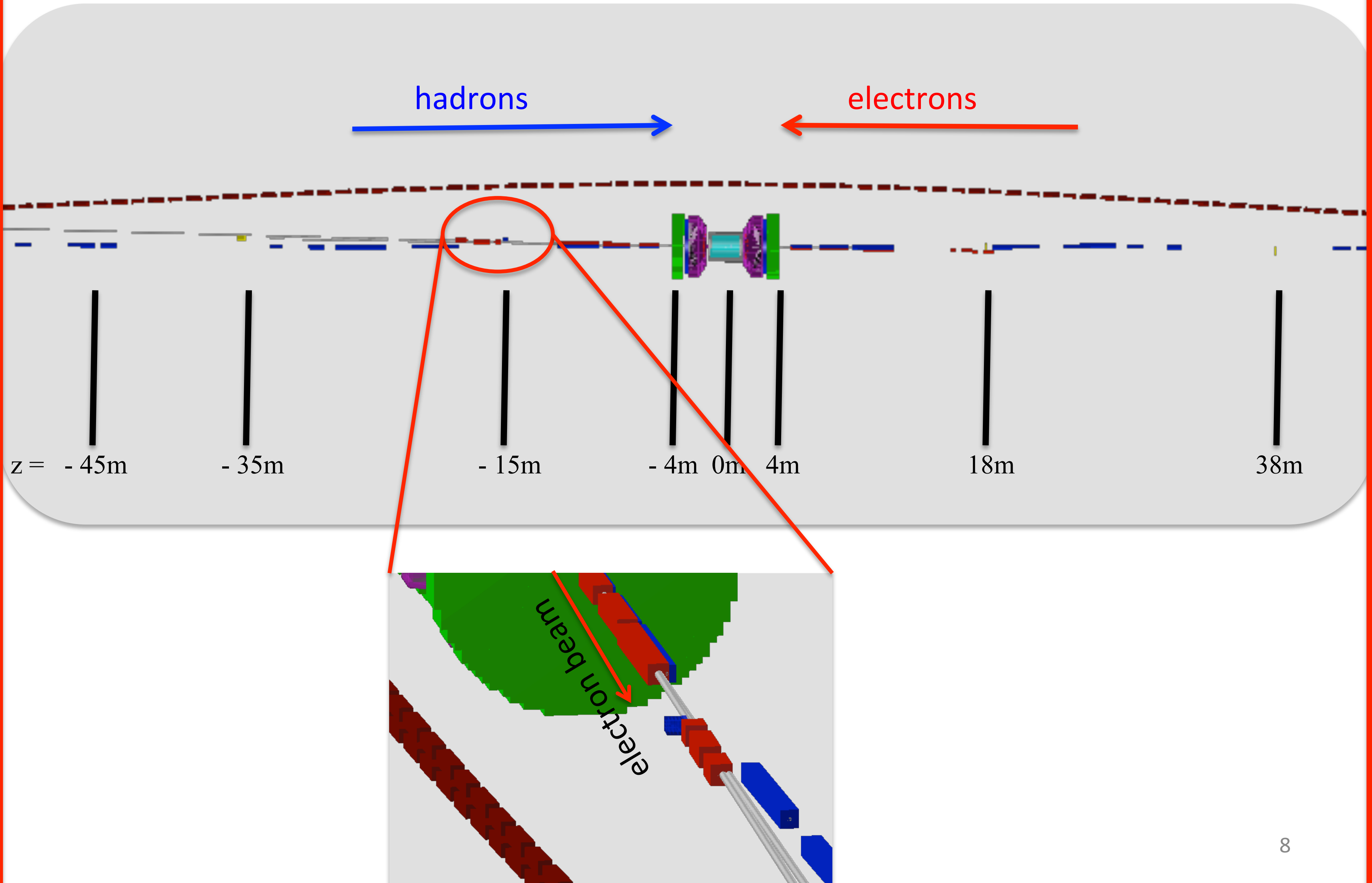
A Low Q^2-tagger

- Implement a dedicated electron detector for tagging low Q^2 events
- Electrons from these events scatter at very small angle and are outside main detector acceptance
- Machine designed so that apertures are rather large in the outgoing electron direction
- Current idea is to have a calorimeter with tracking layers in front
- Place as close to the beam as possible to maximize acceptance
- Outside of primary synchrotron radiation fan



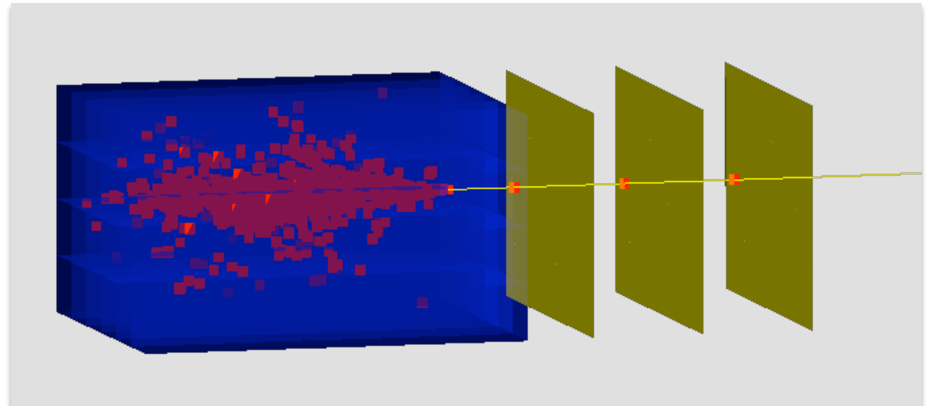
courtesy of Brett Parker (BNL)

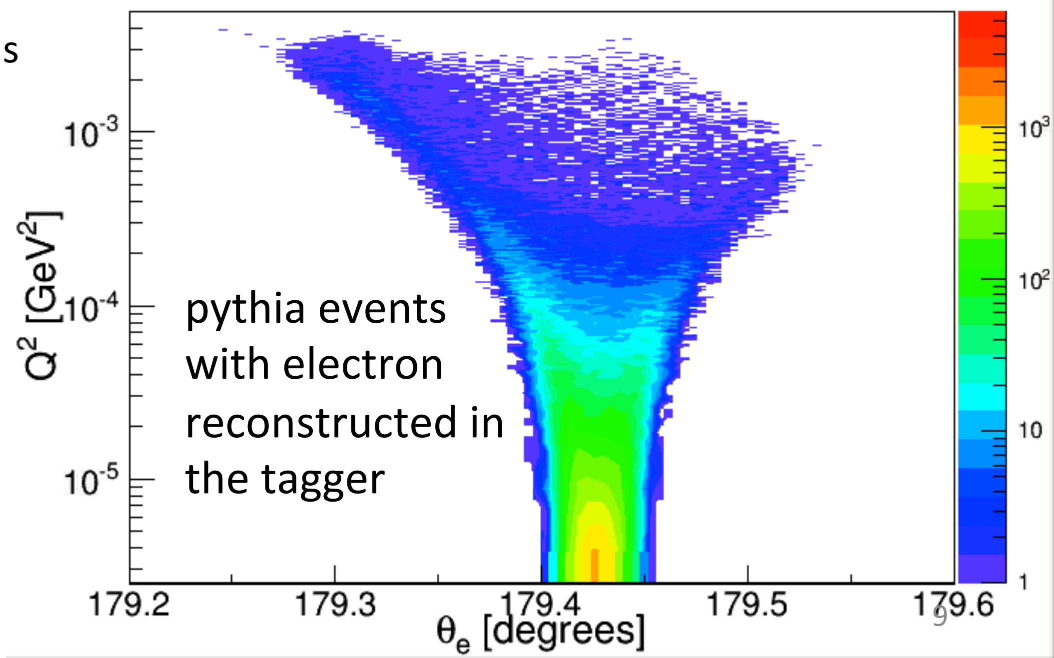
Low Q^2-tagger Placement in the IR



Physics with a Low Q^2-tagger

- Acceptance of electrons from events down to $Q^2 \sim 10^{-5}$ GeV^2
- Allows for further study of photoproduction physics
  - Represents large portion of total cross section
  - Probing the quark structure of photons
    - Direct vs resolved photon
  - Look for change in event properties associated with transition of real to virtual photon





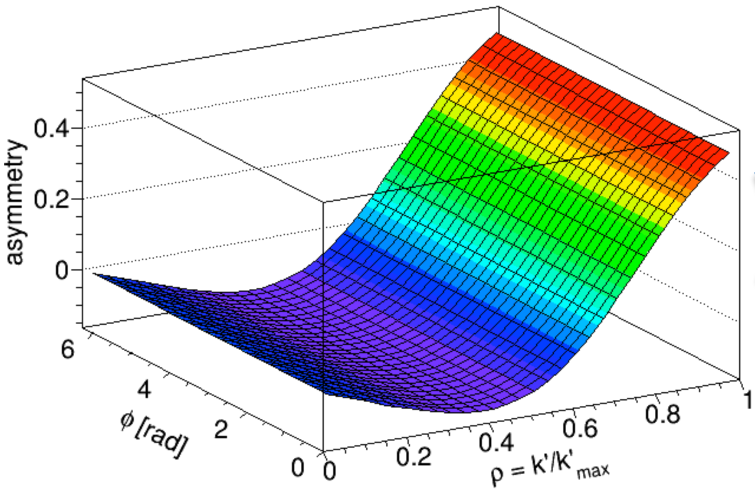
Electron Polarimetry

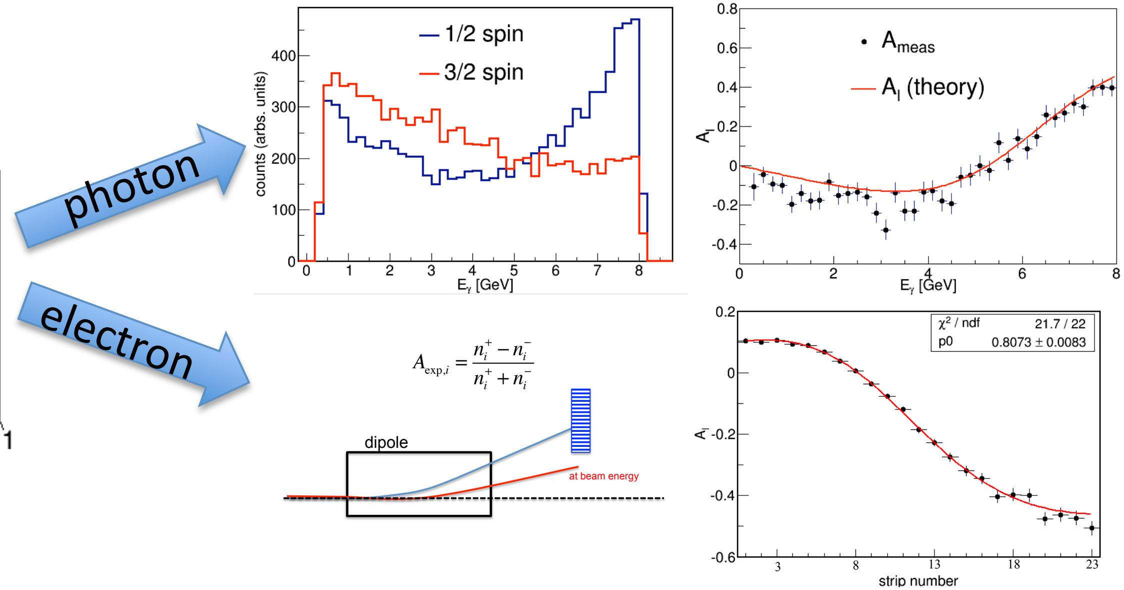
- Need to measure with high precision ~1%
- Compton backscattering will be used to monitor the bunch by bunch polarization
- Compton events produced by shining a laser on the electron beam while flipping the helicity state and measuring the resulting asymmetry
- Can measure either the scattered photon or electron (or both)
- Measure close to the IP and after spin rotators
- Ideally want to measure both longitudinal and transverse components
  - Longitudinal polarization leads to an energy asymmetry
  - Transverse polarization leads to an energy dependent position asymmetry
    - Measure to ensure polarization is fully rotated

$$A_{\exp} = P_e P_\gamma A_\ell$$

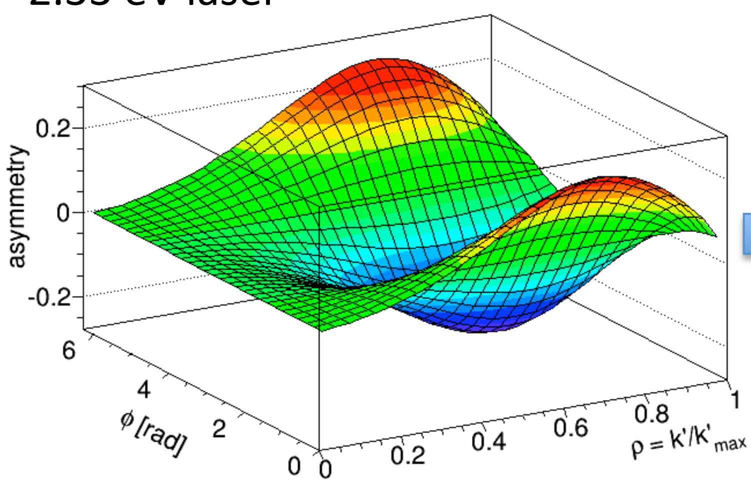
Compton Scattering

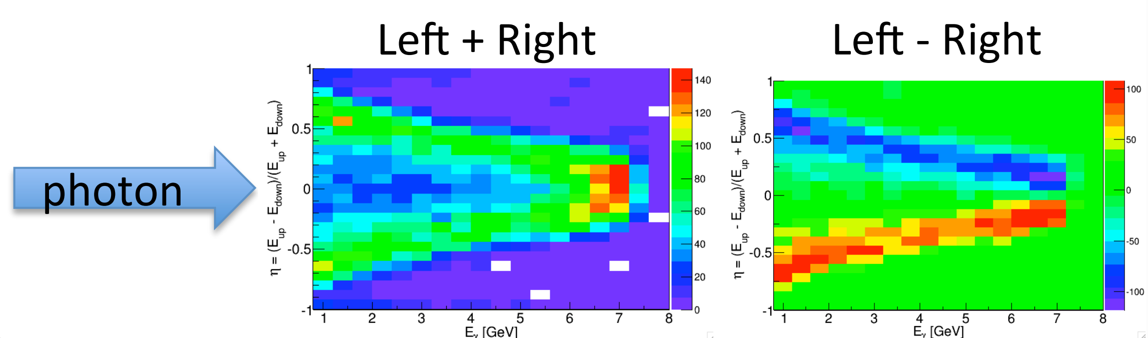
Longitudinally polarized 20 GeV beam
2.33 eV laser





Transversely polarized 20 GeV beam
2.33 eV laser





A Possible Implementation of the Polarimeter

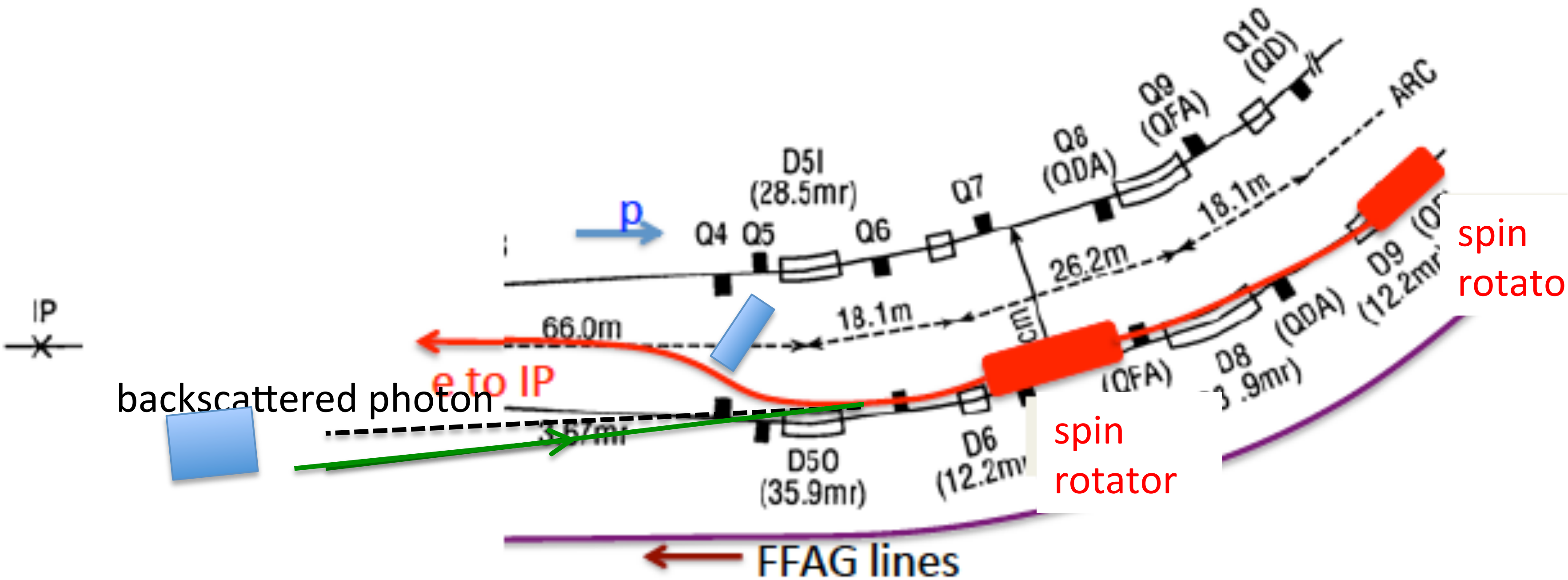
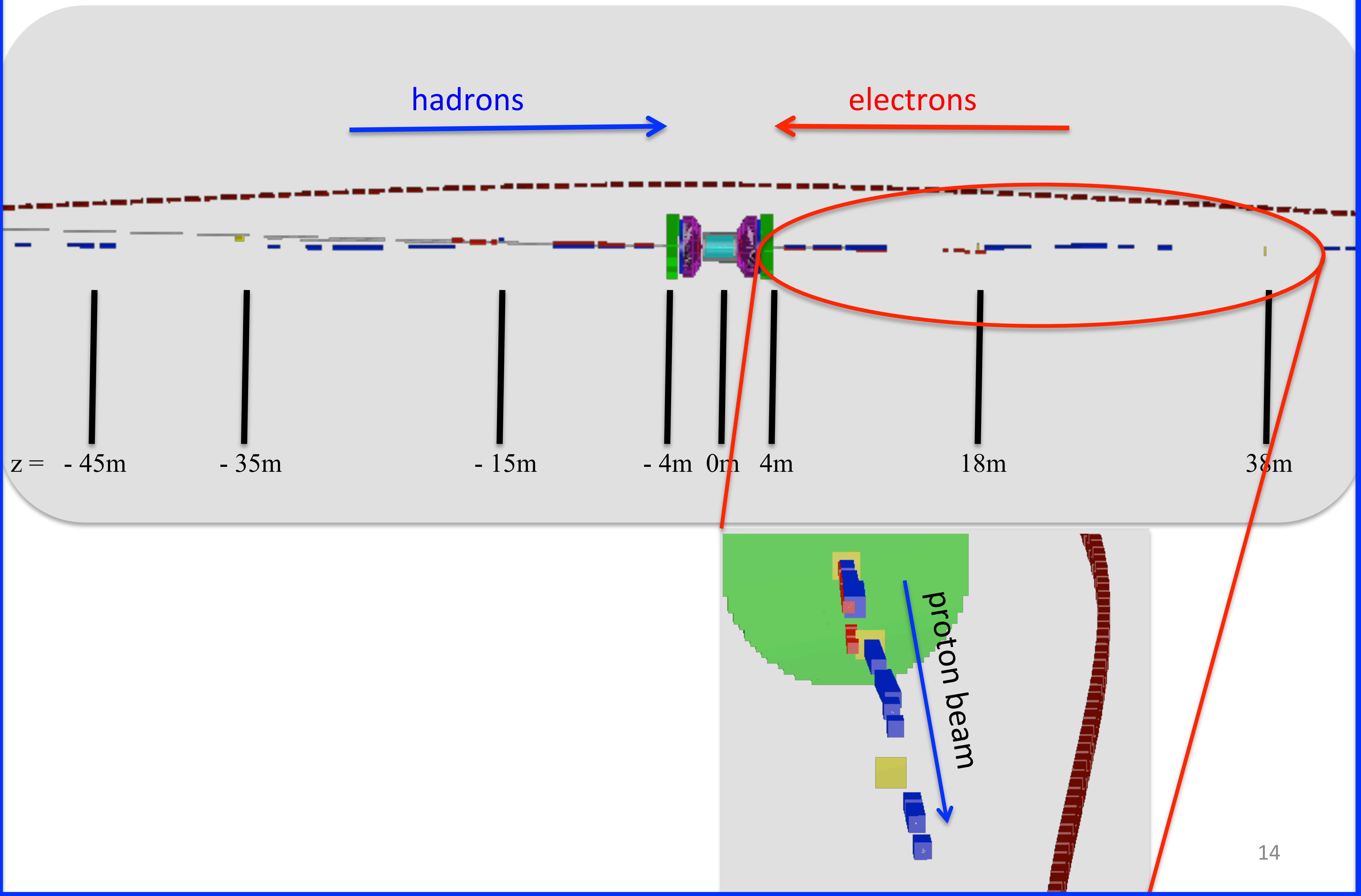


figure courtesy of Vadim Ptitsyn (BNL)

Forward Proton Tagger

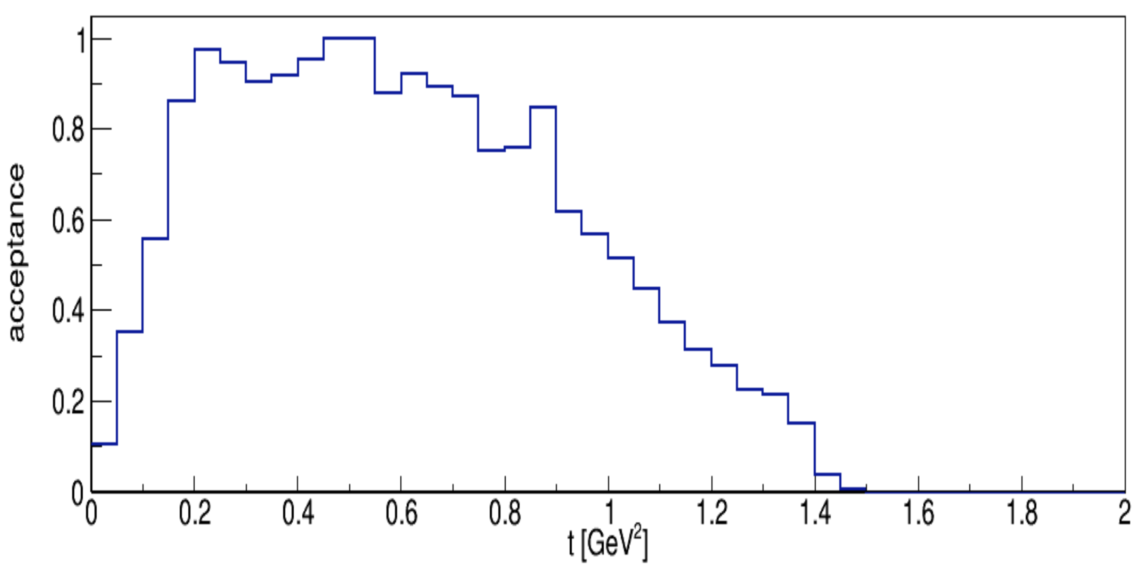
- Considering installation of roman pots
  - Sensors can be moved in and out
  - Designed to go as close to the beam as is safely possible
  - This maximizes acceptance for forward going particles
- Essential to tag forward going protons in exclusive reactions
  - For example exclusive DVCS events
  - Will allow study of GPDs

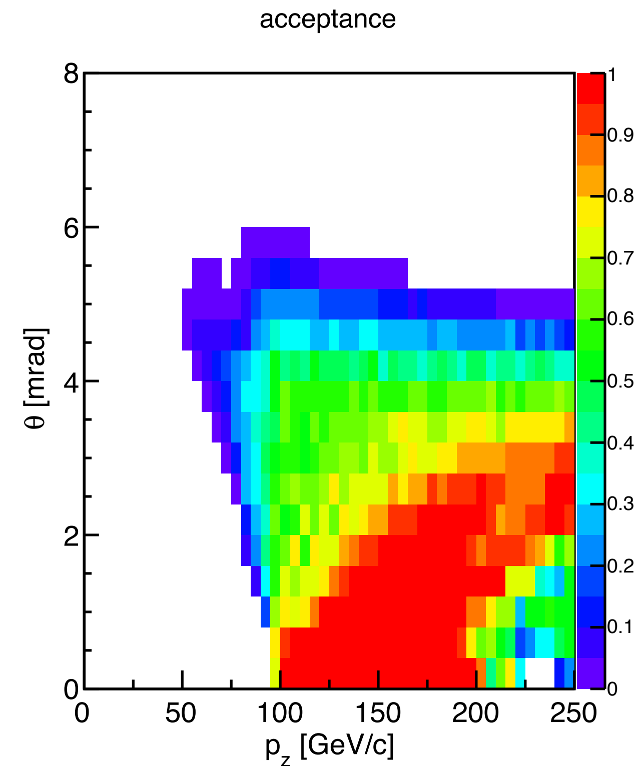
A Possible Forward Proton Tagger Implementation



Roman Pot Acceptance: One Station at 18m

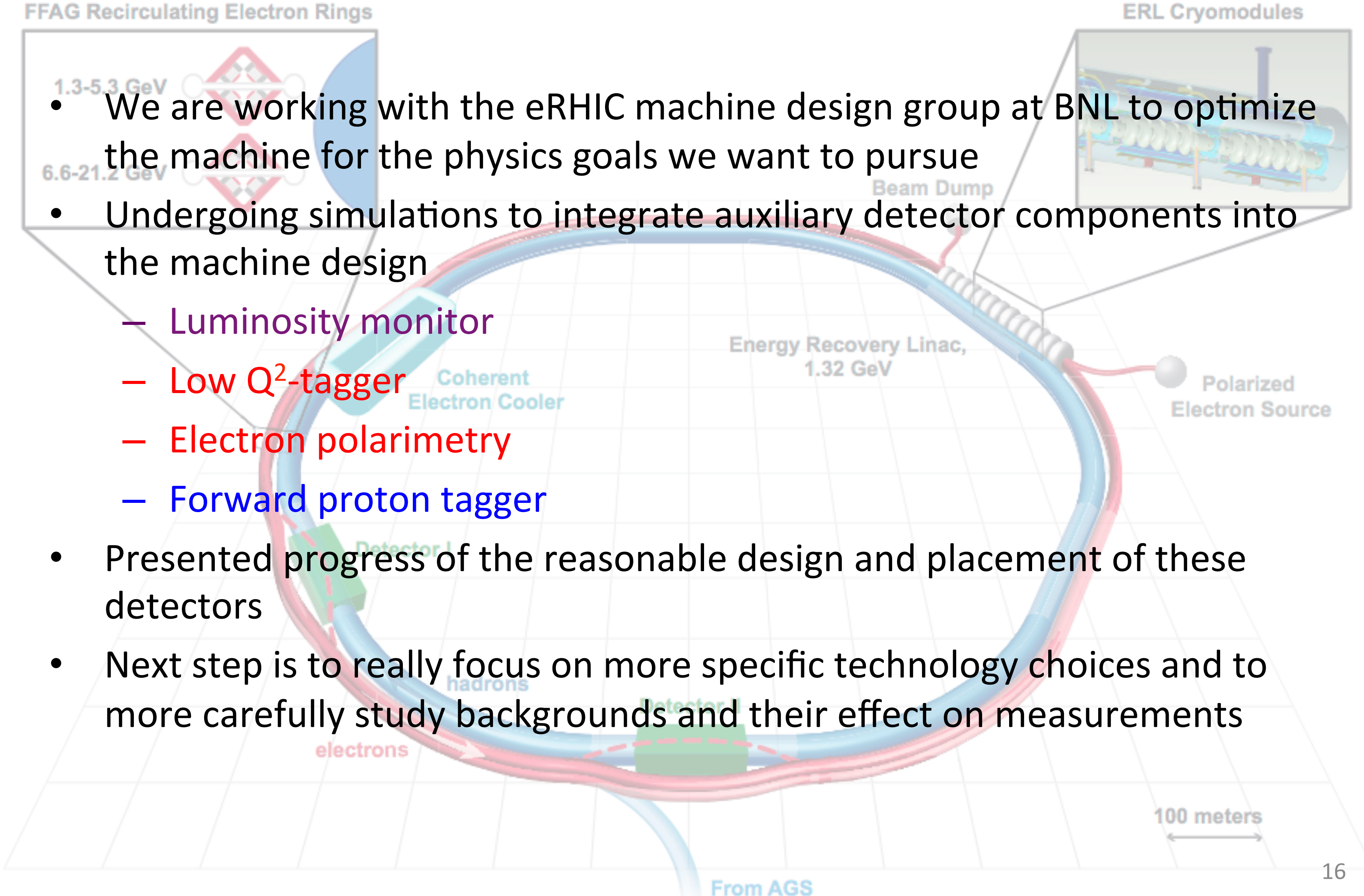
- Feed in MILOU simulations of DVCS events
  - Following studies have no beam effects taken into account and event production at (0,0,0)
  - acceptance suffers at high |t| where protons hit the first magnet yoke
  - we made need something very close to the main detector to get this acceptance





Summary

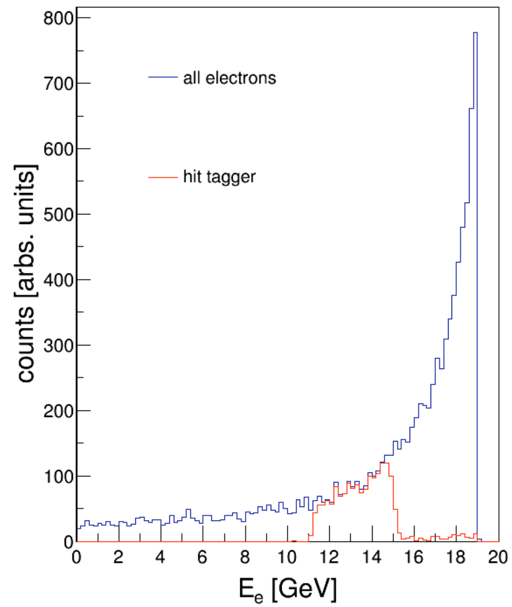
- We are working with the eRHIC machine design group at BNL to optimize the machine for the physics goals we want to pursue
- Undergoing simulations to integrate auxiliary detector components into the machine design
  - Luminosity monitor
  - Low Q^2-tagger
  - Electron polarimetry
  - Forward proton tagger
- Presented progress of the reasonable design and placement of these detectors
- Next step is to really focus on more specific technology choices and to more carefully study backgrounds and their effect on measurements



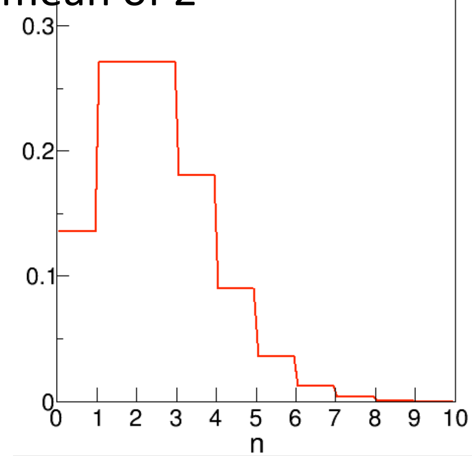
Backups

Background Considerations in the Low Q^2-tagger

- A major background is the ep bremsstrahlung
  - High rate
- Based on 10^{33} cm^{-2} s^{-1} luminosity and 20x250 GeV ep collisions, expect roughly 2 brem. electrons per bunch crossing hitting the tagger
- Brem. rate much larger than photoproduction rate
  - $O(10^3)$ difference in rates
- Can veto these events
  - Look for coincidence in the lumi monitor
  - Ensure no activity in the main detector



poisson distribution with mean of 2



The equations from QED for Compton Scattering

total cross section: $$\frac{d^2\sigma}{d\rho d\phi} = \frac{d^2\sigma_0}{d\rho d\phi} \mp P_e P_\gamma \left(\cos\psi \frac{d^2\sigma_1}{d\rho d\phi} + \sin\psi \cos\phi \frac{d^2\sigma_2}{d\rho d\phi} \right)$$

unpol. contrib.: $$\frac{d^2\sigma_0}{d\rho d\phi} = r_0^2 a \left[\frac{\left(\rho(1-a)\right)^2}{1-\rho(1-a)} + 1 + \left(\frac{1-\rho(1+a)}{1-\rho(1-a)} \right)^2 \right]$$

long. pol. contrib.: $$\frac{d^2\sigma_1}{d\rho d\phi} = r_0^2 a \left[\left(1-\rho(1+a)\right) \cdot \left(1 - \frac{1}{\left(1-\rho(1-a)\right)^2} \right) \right]$$

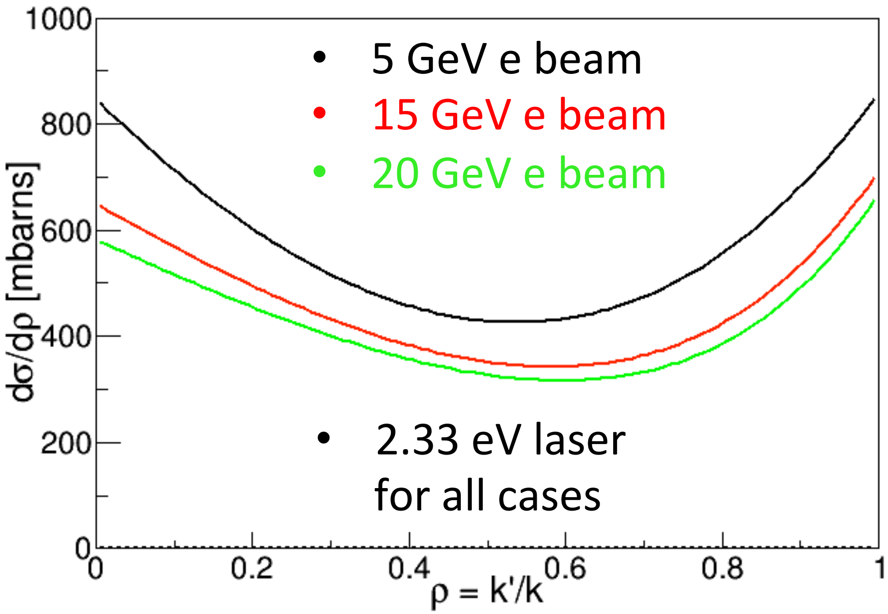
trans. pol. contrib.: $$\frac{d^2\sigma_2}{d\rho d\phi} = r_0^2 a \left[\rho(1-a) \frac{\sqrt{4a\rho(1-\rho)}}{1-\rho(1-a)} \right]$$

- ψ is the angle of the spin vector to the direction of particle momentum
- Φ is the azimuthal angle in the lab frame
- ρ is the scattered photon energy (relative to the Compton edge)
- a is a kinematical factor related to the electron beam energy and laser photon energy

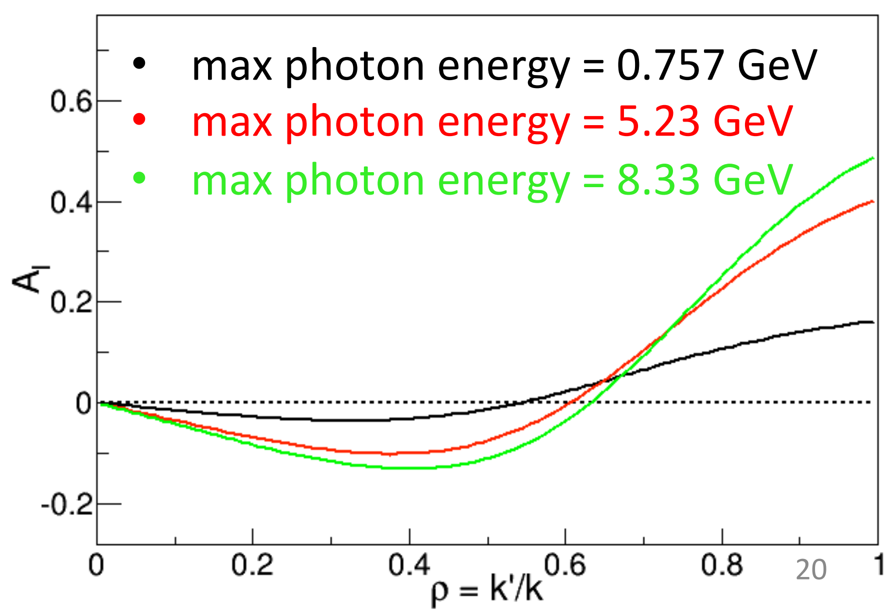
Compton Scattering

- Most probable energy of scattered photon is at the Compton edge
- Scattered photons highly collimated in electron beam direction
- Fairly large analyzing power at the Compton edge

Cross section

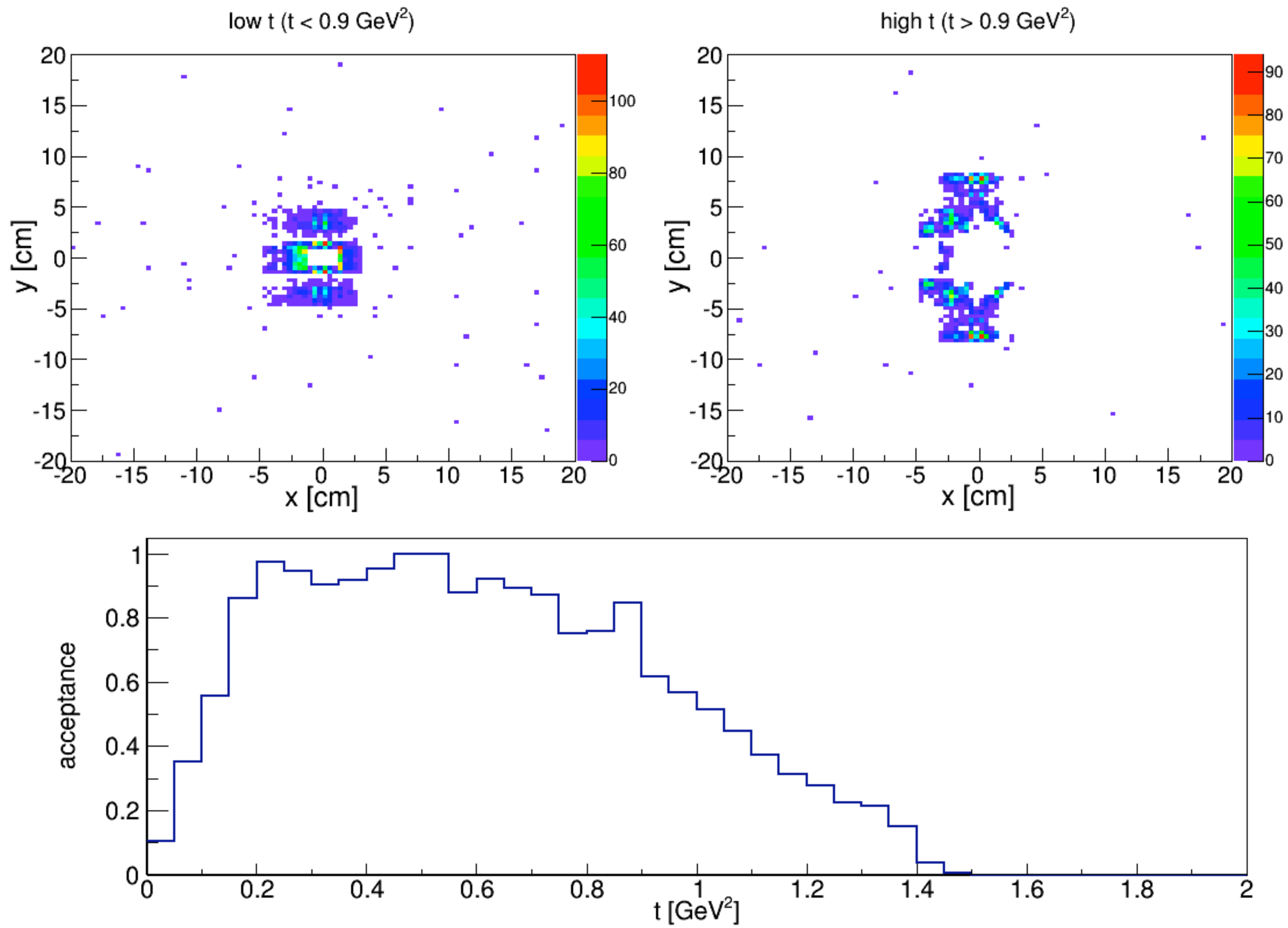


Longitudinal asymmetry (analyzing power)



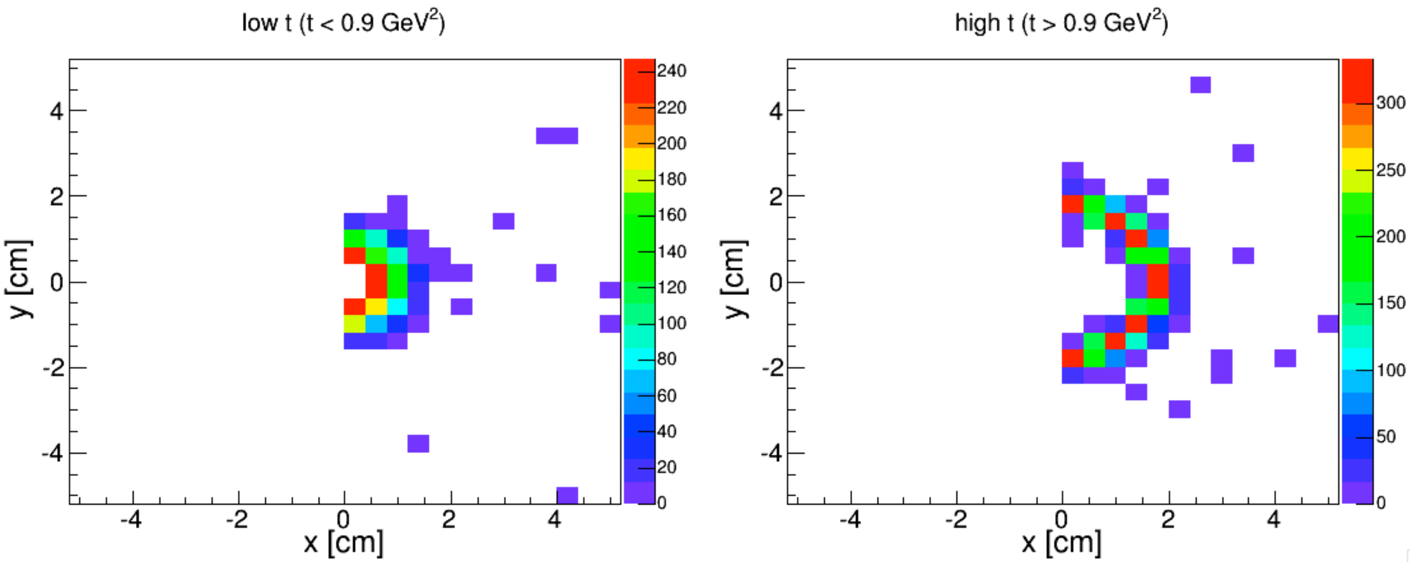
Roman Pot Acceptance: One Station at 18m

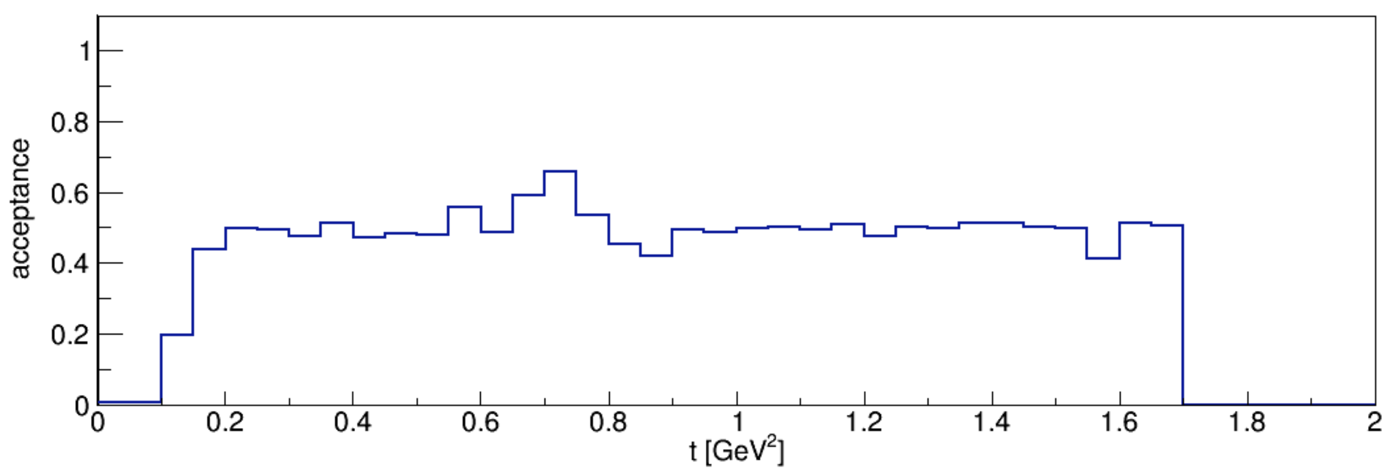
- Feed in MILOU simulations of DVCS events
  - Following studies have no beam effects taken into account and event production at (0,0,0)
  - Coordinates relative to the center of the beam



Addition of a close station at 4.25m

- necessary for acceptance at high t (most statistics starved phase space)
- electron beam prevents full 360^{O} acceptance





Investigating the size of the bremsstrahlung photon cone

- Want to ensure that the bremsstrahlung photon cone has good acceptance in the IR design
- Look at simulations from $e+p \rightarrow e+p+\gamma$ (unpolarized) from DJANGOH
- also compare to toy simulation of photons pulled from the Bethe-Heitler calculation
- fold in effect of beam optics
  - angle smearing from angular beam divergence
  - steering of vertex position also studied

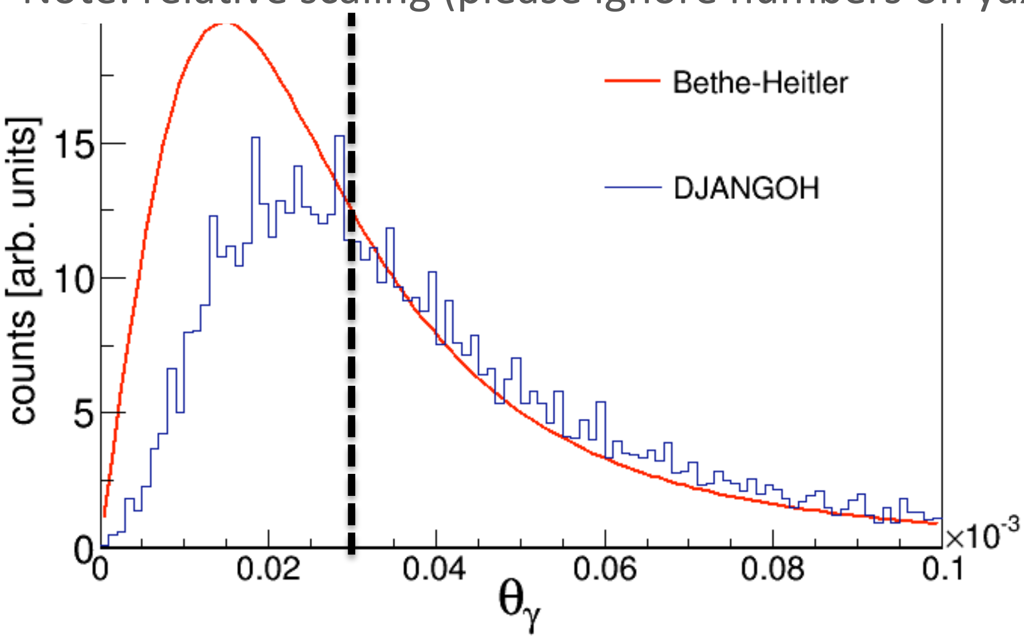
Lumi monitor study – the e+p → e+p+γprocess

- Two estimates of the expected angular distribution of Bremsstrahlung photons
  - Bethe-Heitler calculation

$$\frac{d\sigma}{d\Theta_\gamma} \approx \frac{\Theta_\gamma}{\left(\left(m_e/E_e\right)^2 + \Theta_\gamma^2\right)^2}$$

  - DJANGOH simulation
    - MC generator for DIS and bremsstrahlung processes

Note: relative scaling (please ignore numbers on yaxis)



- typical angle of emission is less than 0.03mrad
- roughly factor of 10 less than contribution from beam divergence for top energy ep collisions (see next slide)
- +/- 4mrad cone is the approximate space available

Luminosity monitor study – beam optics

- calculation of the angular beam divergence (in radians)

$$\sigma_\theta = \sqrt{\frac{\varepsilon}{\beta^* \gamma}}$$

  - sigma_theta = angular beam divergence
  - epsilon = (normalized) emittance (taken from table 3-1 of the eRHIC design report)
  - gamma = lorentz factor
  - beta* = beam optics parameter at IP (5cm taken from table 3-1)

- for 20x250 GeV e+p collisions

$$\sigma_\theta = \sqrt{\frac{23\times10^{-6}}{0.05*5\times10^{4}}} = 0.1mrad$$

- for other beam conditions